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SAMPLING METHOD AND TIME DETERMINES COMPOSITION OF SPIDER COLLECTIONS

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ABSTRACT. Sampling methods and times can misrepresent components of spider assemblages found in tree crops. I collected 2561 spiders, including 20 families, 77 genera and 140 species, from inland and coastal south-east Queensland citrus orchards maintained under Integrated Pest Management programs. Spider assemblages, collected diurnally and nocturnally using vacuum and pit-trap sampling methods over four seasonal periods (spring, summer, autumn and winter), were compared using Simpson and Shannon-Wiener diversity indices and Morisita-Horn similarity index. Significantly different spider assemblages were collected by the two sampling methods in all orchards and seasons. Nocturnal and diurnal sample data differed for spider abundance (similarity) and diversity for several orchards. These results indicate the need to conduct nocturnal and diurnal sampling using a combination of sampling methods to reduce misinterpretation of the composition of spider assemblages. Such misinterpretations may underestimate the predatory importance of spiders in agricultural ecosystems.

Spiders are gaining favor in ecological studies as indicators of environmental quality (Clausen 1986; Maelfert et al. 1990; Churchill 1997), and as biological control agents in agricultural ecosystems (Riechert & Lockley 1984; Young & Lockley 1985; Nyffeler & Benz 1987; Bishop & Riechert 1990). Knowledge of field populations of spiders, and the sampling techniques for gaining that knowledge, are therefore of great importance.

Different collecting methods can misrepresent certain components of spider assemblages (Merrett & Snazell 1983; Churchill 1993). For instance, pitfall traps, which are commonly used for spider collecting, are effective for ground-dwelling spiders but underestimate the diversity and abundance of the foliage-dwelling fauna. Many surveys of spiders in agricultural ecosystems employ pit-traps alone (Alderweireldt & Desender 1990; Vangsgaard et al. 1990). Canopy fogging (Basset 1990; Russell-Smith & Stork 1995) underestimates web-building and web-producing spiders which can remain attached to their webs or suspended in foliage after the insecticide treatment. Branch beating can under-represent web-building spiders. For instance, *Neoscona oaxacensis* (Keyserling) did not constitute a high percentage of spiders collected by branch-beating in vineyards, although the webs and spiders were numerous and highly visible between rows of vines (Costello & Daane 1995).

Fewer spiders were collected by vacuum sampling than pitfall trapping in heathland (Merrett 1983). Fogging is not an option in orchards under Integrated Pest Management as imported biological control insects may be unnecessarily destroyed, and branch-beating at night is not successful as escaping spiders are not easily seen in poor light (Green unpubl. data). Consequently, vacuum suction, in conjunction with pit-fall trapping, is chosen for this study. Merrett & Snazell (1983) recommend a combination of vacuum and pit-trapping for sampling spiders in heathland and De Barro (1991) advocates the use of a two stroke gasoline-driven blower vacuum for aphids on wheat.

The temporal dimension to spider foraging behavior must also be considered. Diurnal and nocturnal sampling appear necessary to effectively sample all of the spider fauna as many spiders are nocturnal (Coddington et al. 1990). Most studies which use several methods, such as hand collecting, sweep nets or vacuum samples, are usually conducted during daylight hours (Young & Lockley 1990; Mason 1992; Breene et al. 1993a, b). Some studies include nocturnal samples or observations of spider assemblages (Coddington et al. 1990; Coddington et al. 1996; Dobyns 1997).

Sampling methods should be kept to a mini-

mum to reduce complexity in the sampling protocol, and methods chosen should minimize species overlap by collecting different spider assemblages (Coddington et al. 1990). Here I demonstrate the importance of a combination of two sampling methods, in this case vacuum and pit-trap, and sampling times, diurnal and nocturnal, for determining the numerically abundant spider species in citrus orchards.

STUDY AREA AND METHODS

Study locations.—Spiders were collected from two inland (Mundubbera 25°35′S, 151°18′E, 300 km from the coast) and two coastal (Coochin Creek 26°54′S, 53°05′E) citrus orchards in south-east Queensland, Australia; the orchards are under an Integrated Pest Management (IPM) program which has been developed around biological control and the limited use of pesticides. Consequently, higher numbers of native natural enemies like spiders are conserved than in chemically managed orchards. Sampling was conducted diurnally and nocturnally over four seasons from Spring 1993 to Winter 1994. Sampling took place over the middle month of each season. Replicates in each orchard were sampled once per season. Sampling occurred under suitable weather conditions for spider collection, temperatures between 5–38 °C and no rain. Ellendale mandarins and Navel oranges from inland orchards, and Valencia and Navel oranges from the coastal orchards were sampled.

Sampling methods.—Four groups of six trees each were randomly selected in each orchard in each season, giving a total of 24 trees sampled per orchard per season. Within each group of six trees, three trees were sampled diurnally and three were sampled nocturnally. Vacuum-sampling was carried out for 15 minutes per tree between 0630–1030 h for diurnal samples and between 1800–2200 h for nocturnal samples. Nocturnal sampling was effected by wearing a headlamp. Foliage, trunk and branches were sampled on each tree to the height of the author's reach plus the length of the sampler (about 2.5 m).

A Little Wonder Power Blower™ (Model 9444E, Korditz, Japan) powered by a two-stroke gasoline motor was used for suction sampling. The only modification, a net sleeve, was placed inside the muzzle of the vacuum to facilitate spider collection. After suction sampling, spiders were placed into labelled killing jars containing ethyl acetate before being transferred, in the laboratory, to labelled glass vials containing 70% EtOH.

Pit-traps consisted of plastic food containers (115 mm diameter, 80 mm deep) which were three-quarters filled with detergent and water (1:40). The traps were placed in the ground, so that the soil was flush with the rim, one trap under each of three trees (about 7.3 m apart) in each block of six trees. The containers were left open for one week. Specimens collected from pit-traps were placed into labelled glass vials containing 70% alcohol.

Data analysis.—Diversity analysis, using 10,000 randomizations, determined the significance of observed differences in community structure between two sampling methods and two sampling times based on species abundance distributions (Solow 1993). Two diversity indices used are the Shannon-Wiener index, which is sensitive to changes in the abundance of rare species in a community, and the Simpson index, which is sensitive to changes in the most abundant species in a community (Solow 1993). Shannon-Wiener index, which increases with the number of species in the community, is an ordinal scale. An index of 2 does not suggest that community is twice as diverse as a community with an index of 1. The values for Simpson's index vary between 0 (for a sample with high diversity) and 1 (for a sample dominated by a few species) (Solow 1993). Shannon-Wiener index is defined as:

$$H = -\Sigma_i \log p_i$$

where: p_i = the observed relative abundance of a particular species (Solow 1993). Simpson index is defined as:

$$D = \frac{\Sigma n_i(n_i-1)}{[N(N-1)]}$$

where: n_i = the number of individuals of species i, and $N = \Sigma n_i$ (Solow 1993). Two-tailed tests were used to test the hypotheses that the two sampling methods (pit-trapping and vacuum sampling) and sampling at different times of the day (diurnal and nocturnal) collect different abundance and composition of spider assemblages.

The Morisita-Horn index (Wolda 1981; Krebs 1989) was used to calculate similarity

Table 1.—Shannon-Wiener (H) and Simpson (D) diversity indices and Morisita-Horn similarity indices (MH) for vacuum and pit-trap samples in three IPM orchards during four seasons. *n* = total number of genera collected by each sampling method; Diff. = difference between diversity indices for vacuum and pit-trap sampling methods.

		n		H			D			
Season	Orchard	Pit	Vac	Pit	Vac	Diff.	Pit	Vac	Diff.	MH
Summer	Coastal	1	14	0.00	2.16	−2.16	1.00	0.18	0.82	0.000
	Inland 1	4	25	0.93	2.17	−1.24	0.51	0.18	0.33	0.004
	Inland 2	6	31	0.57	2.38	−1.81	0.77	0.20	0.57	0.002
Autumn	Coastal	4	26	0.63	2.36	−1.73	0.69	0.18	0.51	0.003
	Inland 1	6	17	1.26	2.58	−1.32	0.41	0.09	0.32	0.010
	Inland 2	6	28	0.38	2.62	−2.24	0.86	0.11	0.75	0.000
Winter	Coastal	2	22	0.44	2.81	−2.37	0.73	0.07	0.65	0.000
	Inland 1	3	18	0.60	2.00	−1.40	0.68	0.25	0.43	0.003
	Inland 2	4	20	0.56	2.52	−1.97	0.75	0.11	0.64	0.013
Spring	Coastal	5	25	1.23	2.33	−1.11	0.35	0.15	0.20	0.000
	Inland 1	7	24	1.18	2.65	−1.47	0.41	0.09	0.32	0.008
	Inland 2	6	43	1.09	2.80	−1.71	0.47	0.09	0.38	0.106

(or non-similarity) between spider populations from two sampling methods and two sampling times. The index is independent of sample size and diversity (Wolda 1981) and is an appropriate measure to compare community structure in day and night sampling using vacuum and pit-trap sampling methods. The Morisita-Horn index was calculated from:

$$MH = \frac{2\Sigma n_{1i} n_{2i}}{(\lambda_1 + \lambda_2) N_1 N_2}$$

where MH = Morisita-Horn index of similarity between sampling methods *j* and *k*, n_{1i} = the number of individuals of species *I* in sample *j*, N_1 = the total number of individuals of all species in sample *j*, and λ_1 =

$$\frac{\Sigma N_{1i}^2}{N_2^2}$$

Diversity and similarity indices were achieved using spider abundance at the genus level to minimize false results from rare species. This study is part of a larger project which investigated the potential of spiders as natural pest control agents in citrus orchards in south-east Queensland.

RESULTS

I collected a total of 2561 spiders, including 20 families, 77 genera and 140 species. All spiders, including immatures (29%), were identified to genus or species with the help of Dr. Robert Raven, Queensland Museum.

Effect of sampling method.—For each orchard in each season, diversity indices for genera differed significantly between vacuum sampling and pit-trapping using either Shannon-Wiener (H) or Simpson (D) analyses ($P < 0.0001$, Table 1). Differences were also apparent at family and species level (Table 1). Similarity values differed markedly for each orchard in each season; all values were below 0.01 (Table 2).

Generic composition was markedly different for each sampling method. Only 13 species (10%), 13 genera (18%) and 8 families (40%) were common to both methods. Combined data for all orchards in all seasons showed that at all taxonomic levels, more taxa were collected by vacuum sampling than by pit-traps (Fig. 1A). No lycosids or zodariids, and few gnaphosids and corinnids, were collected by vacuum sampling. Spiders from these families are ground-dwelling spiders. Some salticids were collected in pit-traps but the vast majority were found in the upper stratification of the orchard. Different spider communities were seen in the orchard for the two main stratification layers—trees (81–97% of total taxa) and ground (29–57% of total taxa).

Effect of sampling time.—Pit-traps were left open for one week continuously; consequently these data are not included in the diurnal/nocturnal analysis. Generic richness was significantly different between diurnal and

Table 2.—Shannon-Wiener (H) and Simpson (D) diversity indices, their *P*-values, and Morisita-Horn similarity indices (MH) for diurnal and nocturnal samples in three IPM orchards during four seasons. *n* = total number of genera collected in each time period; Diff = difference between diversity indices for diurnal and nocturnal sampling periods.

		n		H				D				
Season	Orchard	AM	PM	AM	PM	Diff.	*P*	AM	PM	Diff.	*P*	MH
Summer	Coastal	6	10	1.42	2.02	−0.6	<0.0001	0.32	0.17	0.15	<0.0001	0.645
	Inland 1	17	19	1.95	2.46	−0.51	<0.0001	0.21	0.13	0.08	<0.0001	0.748
	Inland 2	23	22	2.26	2.24	−0.02	<0.7	0.19	0.21	0.02	<0.0001	0.963
Autumn	Coastal	18	17	2.15	2.08	0.07	<0.3	0.18	0.22	−0.03	<0.0001	0.869
	Inland 1	15	10	2.12	2.46	−0.34	<0.001	0.13	0.09	0.04	<0.0004	0.510
	Inland 2	21	21	2.42	2.36	0.06	<0.3	0.14	0.14	−0.004	<0.5	0.821
Winter	Coastal	15	15	2.54	2.56	−0.02	<0.7	0.09	0.08	0.004	<0.6	0.663
	Inland 1	14	14	1.94	1.91	0.04	<0.4	0.25	0.25	−0.009	<0.06	0.983
	Inland 2	14	17	2.35	2.43	−0.07	<0.2	0.12	0.12	0.003	<0.6	0.825
Spring	Coastal	21	22	2.56	2.61	−0.04	<0.5	0.10	−0.11	−0.01	<0.7	0.912
	Inland 1	18	19	2.48	1.5	0.99	<0.0001	0.11	−0.42	−0.31	<0.0001	0.283
	Inland 2	24	24	2.56	2.48	0.08	<0.05	0.10	−0.11	−0.01	<0.01	0.701

nocturnal sampling in 42% (Shannon-Wiener) and 58% (Simpson) of samples over four seasons ($P < 0.05$) (Table 2). Although Shannon-Wiener indices for diurnal and nocturnal collections from two orchards (Summer Inland 2, Autumn Coastal) showed no difference ($P < 0.3$), Simpson indices were significantly different ($P < 0.05$). Numerical dominance by some species (i.e., *Zenodorus orbiculatus* (Keyserling), Salticidae, and *Cyrtophora moluccensis* Doleschall, Araneidae) was considerably higher in diurnal than nocturnal samples in Summer Inland 2, while dominance varied between diurnal and nocturnal collections in Autumn Coastal. The sensivity to dominance of the Simpson's index may account for this result. Inland 1 showed significant differences between the two collection times in all seasons (Table 2). Greater numbers of spiders collected in the warmer months provide a possible explanation for greater differences in species richness in Summer, Spring and Autumn than in Winter (Table 2).

Morisita-Horn similarity indices (MH) for diurnal and nocturnal sampling were relatively high in comparison with those for sampling methods. Most MH values for sampling times corresponded with the diversity indices, i.e., similar MH, similar H and D (Table 2). However, while MH and D for Summer Inland 2 showed similarity between the two sampling times, H showed a significant difference. Nine rare species (i.e., < 2 individuals collected) which were not common to both times were collected in this orchard; the significant difference between the two sampling times is a result of the Shannon-Wiener sensitivity to rare species.

Most families were included in collections at both sampling times. Nocturnal spiders, like *Eriophora transmarina*, the clubionid *Cheiracanthium* sp. 'a', and *Heteropoda* sp. 'a', were collected in greater numbers at night than in the day time. Families collected only at night were Deinopidae, Gnaphosidae, Lamponidae and Mimetidae. Combined vacuum data for each orchard in each location in each season show 57–75% of taxa were collected diurnally; 69–87% were collected nocturnally (Figure 1B).

DISCUSSION

Effect of sampling method.—In contrast to this study, pitfall traps collected more spider taxa in heathland than sweep-netting and visual searching (Churchill 1993) or vacuum sampling (Merrett & Snazell 1983). Vegetational architecture plays a major role in the species composition found within a habitat (Scheidler 1990), and vegetation which is structurally more complex can sustain a higher abundance and diversity of spiders (Hatley & MacMahon 1980). Diversity in web-building spiders is significantly correlated with vegetation height (Greenstone 1984) and high species diversity in wandering ground-dwell-

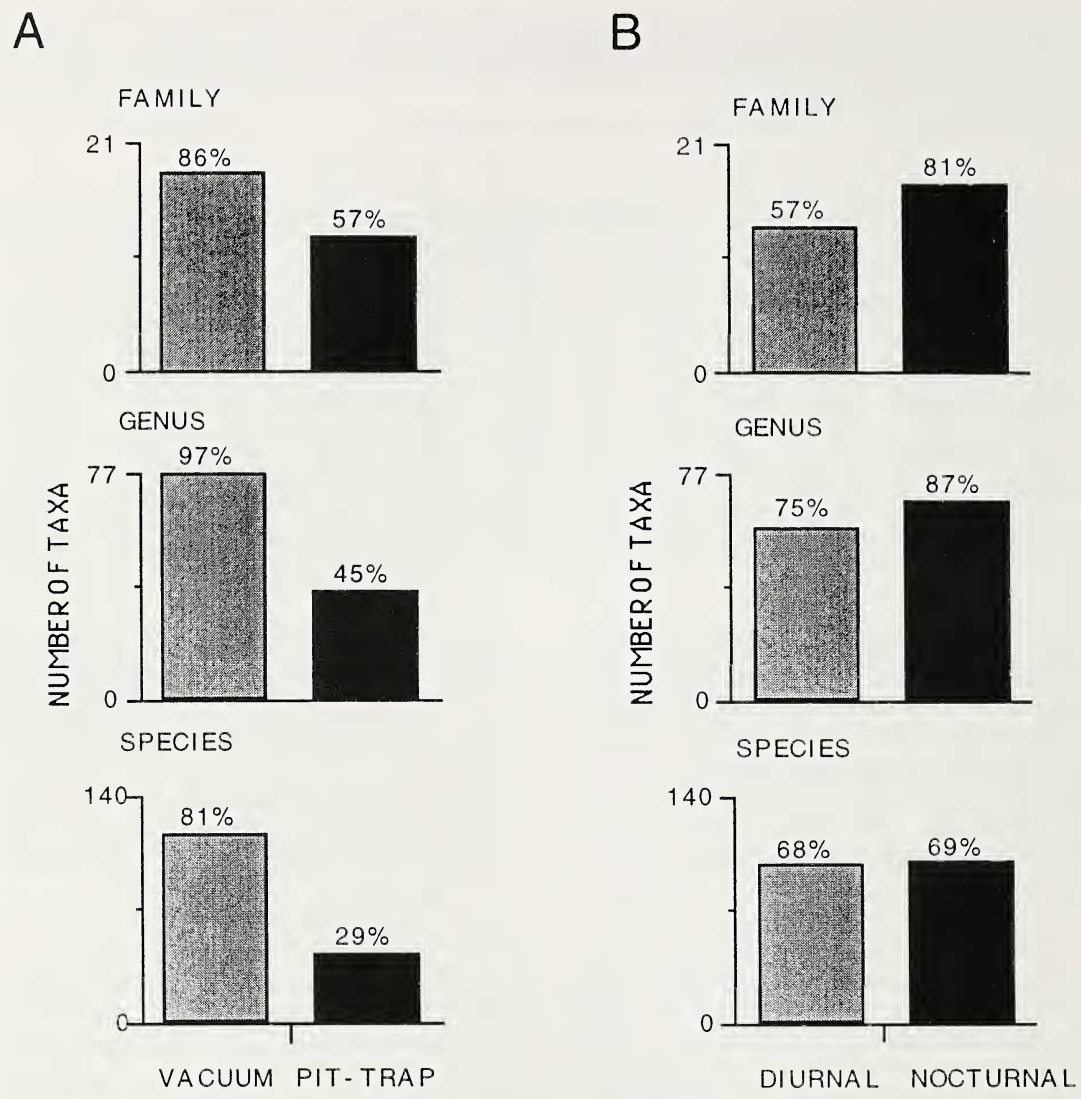

Figure 1.—(A). Total number of taxa caught by vacuum and pit-trap sampling methods (Percentages are of total taxa collected). (B). Total number of taxa caught by diurnal and nocturnal sampling (Percentages are of total vacuum samples—pit-trap data are not included in this analysis).

ing spiders is correlated with large amounts of litter (Uetz 1975; Koch & Majer 1980). The low shrubs and abundant ground cover in Tasmanian heathland (Churchill 1995) differ markedly from the mature (> 2 m high) citrus trees with little understorey. Differences in vegetational architecture at the two sites account for the different community structures seen in foliage and ground-dwelling spiders.

Effect of sampling time.—Although other studies included observation or sampling of nocturnal species, for various reasons such as results were not quantified (Provencher et al. 1988) or results were combined (Costello & Daane 1995), these studies could not be compared with the present study in terms of differences in species diversity, abundance or similarity between nocturnal and diurnal collections.

Coddington et al. (1996) found time of day had no significant bearing on the taxonomic composition of the samples from temperate forests. However, these authors recommend both day and night collecting to maximize the species richness of the samples. In the same temperate forest, abundance of adult spiders

differed significantly between day and night samples, but similarity indices were similar for the two time periods (Dobyns 1997). Tropical forests produced significantly more species in nocturnal samples than the temperate forests (Coddington et al. 1991). This agrees with the present study which was conducted in sub-tropical citrus, suggesting that species differences are greater in tropical forests than in temperate forests and, consequently, that nocturnal predation is higher in sub-tropical and tropical zones.

Sampling times and methods showed different profiles at the family level in spider assemblages. Similarity (MH) indices for differences in sampling times did not all show differences in abundance. However, the results demonstrate the need for different sampling times to provide a more extensive estimate of spider diversity and abundance. Spiders from 4 of 21 families were collected only nocturnally. Had sampling been limited to daylight hours these families would not have been included in the overall composition of the spider assemblage.

In conclusion, this study has established that a combination of sampling methods over two time periods, diurnal and nocturnal, is essential for a comprehensive assessment of the spider fauna to be made, particularly in subtropical areas. The vegetational architecture of a habitat must be taken into consideration before sampling commences. Each sampling method was oriented to different strata of the vegetation and so spiders with contrasting foraging behavior and habitats were collected. Vacuum sampling collected considerably more representatives of each taxonomic level but missed one group of hunting spiders, the ground-dwellers. Pit-trapping is necessary to collect these spiders.

This research has important ramifications in terms of assessing biodiversity of native natural enemies in agricultural ecosystems for pest management, and sampling agricultural crops in general to provide a greater understanding of the composition of all invertebrate fauna including pests and beneficials. A combination of vacuum sampling and pit-trapping, used diurnally and nocturnally is recommended for spider collection in tropical or sub-tropical orchards to sample a greater percentage of the spider fauna.

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